Nuclear Nonproliferation Education Program at Texas A&M University

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Introduction

- TAMU has had a rigorous research and education program in the technical area of nuclear nonproliferation for many years
- This has involved R&D, education, and training in three fundamental areas:
  - nuclear nonproliferation and arms control (from 2003 to present)
  - nuclear safeguards (from 2006 to present)
  - nuclear security (from late 2008 to present)
- This work has largely been led by the Nuclear Security Science and Policy Institute at TAMU
  - a joint institute between the College of Engineering and the Bush School of Government and Public Service

Why Texas A&M University?

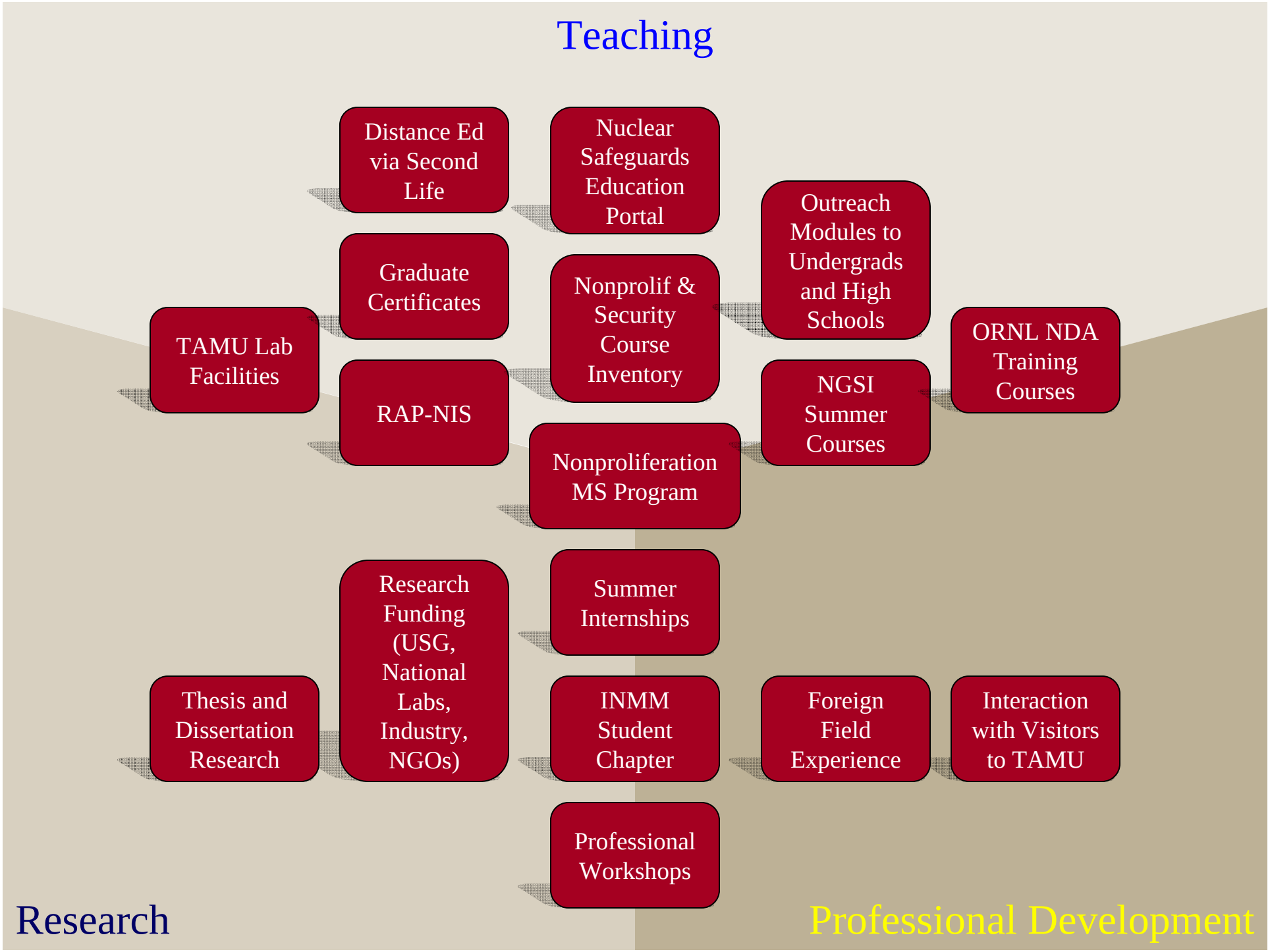
- TAMU has historically had close ties to national laboratories
- TAMU has a long tradition of service to the nation and focus on national missions
  - an all military institution until 1965
  - TAMU produces more commissioned officers than any institution outside the academies
- TAMU has the largest nuclear engineering department in the U.S. and NSSPI
- Knowledgeable faculty

Faculty Competency

- TAMU has the largest nuclear engineering department in the US with 33 faculty:
  - 19 tenure/tenure-track faculty
  - 7 lecturers
  - 3 professor emeritus
  - 1 research professors
  - 3 visiting professors
  - 305 undergraduate students and 121 graduate students
- This allows us to have sizeable expertise in almost every area of nuclear engineering
  - with the exception of fusion and plasma physics
- We have close ties to our Bush School of Government and Public Service

Nonproliferation, Safeguards, and Security Faculty and Staff

- Nuclear Engineering:
  - Adams (post-nuclear event attribution)
  - Boyle (nuclear security and test detection)
  - Charlton (safeguards and security)
  - Chirayath (fuel cycles and safeguards systems)
  - Ford (nuclear terrorism and physical protection)
  - Gariazzo (safeguards systems and C/S)
  - Juzaitis (nonproliferation and arms control)
  - Marianno (field measurements and consequence mitigation)
  - Nelson (nonproliferation and arms control)
  - Poston (radiological terrorism and consequence mitigation)
  - Solodov (NDA instrumentation)
- Policy:
  - Castillo (deterrence)
  - Layne (deterrence and nuclear weapons strategy)
  - Hermann (international affairs)
  - Olsen (national security and intelligence)
- Systems Engineering:
  - Gaukler (systems modeling for nuclear smuggling)
  - Yates (systems and process engineering for safeguards and security systems)
- Mathematics:
  - Rundell (inverse problem analysis for forensics)
- Chemistry:
  - Folden (radiochemistry)
- Computer Science:
  - Bettati (cybersecurity)


Teaching
Distance Ed via Second Life
Nuclear Safeguards Education Portal
Outreach Modules to Undergrads and High Schools
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Nonprolif & Security Course Inventory
TAMU Lab Facilities
ORNL NDA Training Courses
RAP-NIS
NGSI Summer Courses
Nonproliferation MS Program
Research Funding (USG, National Labs, Industry, NGOs)
Summer Internships
Thesis and Dissertation Research
INMM Student Chapter
Foreign Field Experience
Interaction with Visitors to TAMU
Professional Workshops
Research
Professional Development

Nonproliferation and Nuclear Security Specific Course Inventory

Course	Title	Instructor	Times Taught	Average Enrollment
NUEN 650	Nucl Nonproliferation & Arms Control	Charlton	6	24
NUEN 605	Rad Detection & Nucl Materials Measurement	Marianno	3	11
NUEN 651	Nuclear Fuel Cycle & Safeguards	Chirayath, Solodov	4	12
NUEN 656	Critical Analysis of Nuclear Security Data	Charlton	3	6
NUEN 489	Nuclear Security Science	Ford	1	12
NUEN 489	Nuclear Nonproliferation	Juzaitis, Ford	2	30
CHEM 681	Radiochemistry and Nuclear Forensics	Folden	1	8
MATH 644	Inverse Problems in Nuclear Forensics	Rundell	1	18

Nonproliferation Degree Plan Program Elements

- Required
  - 36 credit hour M.S. curriculum
  - M.S. thesis in nuclear nonproliferation, safeguards, or security
    - with 2-3 semesters of funded research
    - students typically work in small teams often with students from other disciplines
- Optional
  - Foreign field experience
  - Fall and Spring 1-week training courses at ORNL
  - Summer internships at national laboratories
  - Summer courses at national laboratories
  - Extra-curricular learning through student chapter of INMM
  - Heavy emphasis on policy courses in addition to technical courses

Nonproliferation Degree Curriculum

	Course Designation and Title	Credit Hours
Fall Year 1	NUEN 650 Nuclear Nonproliferation and Arms Control	3
	NUEN 601 Nuclear Reactor Theory	3
	NUEN 605 Radiation Detection and Nuclear Materials Measurement*	3
	NUEN 681 Seminar in Nuclear Nonproliferation	1
	NUEN 685 Independent Study	2
Spring Year 1	NUEN 604 Nuclear Radiation Shielding	3
	NUEN 606 Nuclear Reactor Analysis and Experimentation	4
	NUEN 651 Nuclear Fuel Cycles and Nuclear Material Safeguards*	3
	NUEN 691 *Research*	2
Fall Year 2	NUEN 656 Critical Analysis of Nuclear Security Data**	4
	Elective	3
	Elective	3
	NUEN 691 *Research*	2

* includes a 1-week practical at ORNL, LANL, or similar venue

** includes a 1-week foreign field experience with Russian students

Course Prerequisites

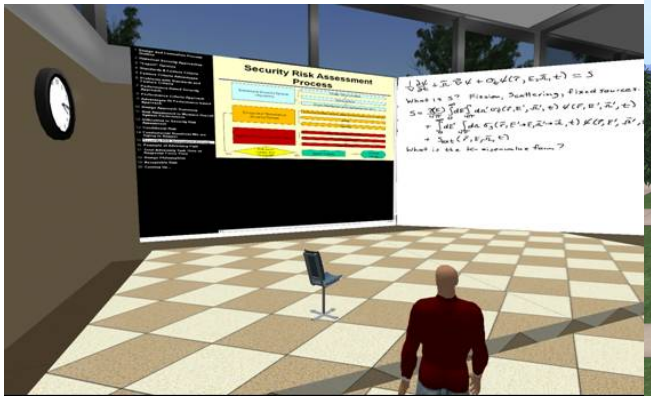
- Since these students are regular graduate students in our Nuclear Engineering Program, the students have most prerequisites necessary to enter these courses
- Students entering this program have a B.S. degree in nuclear engineering or another natural science or engineering discipline
  - thus, they enter with a significant mathematics and physics background
  - but traditionally with a weak policy background
  - and typically little to no operational experience

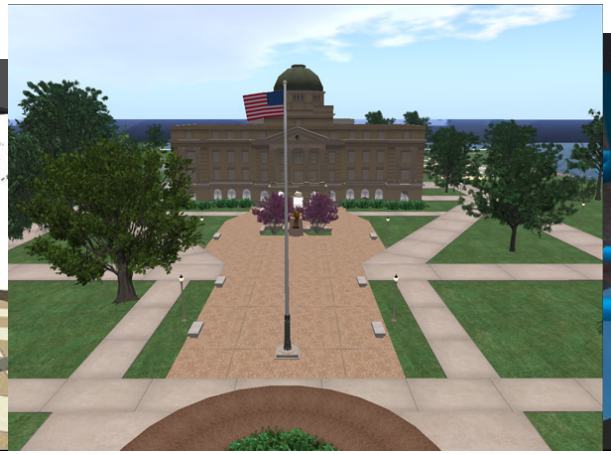
Nuclear Safeguards Education Portal (http://nsspi.tamu.edu/NSEP)

- Module characteristics
  - text, graphics, videos, wikis, quizzes
- Currently deployed:
  - Basics of Radiation Detection
  - Basic Nuclear and Atomic Physics
  - The Nuclear Fuel Cycle
  - Introduction to Statistics
  - Safeguards Terminology
  - Nuclear Material Accountancy
- Since June 2009, NSEP used >1080 times
  - Fuel Cycle (300)
  - Nuclear Physics (280)
  - Radiation Det (500)

Distance Education Using Second Life

- TAMU recently developed a campus in Second Life
  - a 3D virtual world that is an emerging online teaching environment
  - runs on a free client application in which users interact with each other using avatars
  - voice chat and multimedia features are available to facilitate participation in individual and group activities
  - you can explore and build unique, "in-world" virtual properties and points of interest that are only limited to your imagination
- We have now used this environment to teach some of our classes





Recent Theses and Dissertations

- J. Feener, May 2010, “Safeguards For Uranium Extraction (UREX) +1A Process”
- D. Strohmeyer, Dec 2009, “Development of a Portable Neutron-Gamma Coincidence Counter”
- B. Goddard, Dec 2009, “Real-Time Detection of UREX+3a Extraction Streams for Materials Accountancy”
- E. Rauch, May 2009, “Developing a Safeguards Approach for a Small Graphite-Moderated Reactor and its Associated Fuel Cycle Facilities”
- R. Metcalf, May 2009, “New Tool for Proliferation Resistance Evaluation Applied to Uranium and Thorium Fueled Fast Reactor Fuel Cycles”
- J. Miller, Dec 2008, “Analytical Inverse Model for Post-Event Attribution of Plutonium”
- C. Freeman, Aug 2008, “Bayesian Network Analysis of Nuclear Acquisitions”
- D. Sweeney, Aug 2008, “Reactor Power History from Fission Product Signatures”
- A. Thornton, May 2008, “Development of a Portable Neutron Coincidence Counter for Field Measurements … MCNPX 2.5.f and the Neutron Coincidence Point Model”
- D.G. Ford, May 2008, “Assessment Tool for Nuclear Weapon Acquisition Pathways”
- T. Woddi, Dec 2007, “Nuclear Fuel Cycle Assessment of India: A Technical Study for Nuclear Cooperation”
- A. Solodov, May 2007, “Use of Open Source Information and Commercial Satellite Imagery for Nuclear Nonproliferation Regime Compliance Verification by a Community of Academics”
- K. Chesson, May 2007, “Nuclear Archaeology of Graphite Moderated Reactor Systems to Determine Historical Plutonium Production”
- N. Johansen, May 2007, “An Active System for the Detection of Special Fissile Material in Small Watercraft”
- D. Giannangeli, Dec 2006, “Proliferation Resistance Assessments for Closed Fuel Cycles”

Nuclear Forensics Certificate Program

- We have funding from NTNFC to work to establish an interdisciplinary certificate in nuclear forensics
  - Complements academic disciplines that do fundamental research in nuclear forensics areas and other full degree programs
  - Will provide graduates with a broader understanding of nuclear forensics as a technical field of research
- Certificate will consist of 4 graduate courses:
  - NUEN 605 (Radiation Detection and Nuclear Materials Measurement)
  - CHEM 681 (Radiochemistry and Nuclear Forensics)
  - MATH 644 (Inverse Problems in Nuclear Forensics)
  - Summer internship at a national laboratory (SRS or other venue)
  - NUEN 656 (Critical Analysis of Nuclear Security Data) - capstone

NDA Technologies for International Safeguards Classes at ORNL

- Advanced hands-on training including:
  - Handheld isotope identifiers
  - Uranium holdup measurements
  - Object counting systems
  - Isotopic (uranium) enrichment measurements
  - Tours of ORNL facilities and private industry
- Classes held:
  - March 2007 (graduate students)
  - November 2007 (graduate students)
  - May 2008 (undergraduate students)
  - November 2008 (graduate students)
  - May 2009 (undergraduate students)
  - December 2009 (NE & BUSH graduate students)
  - May 2010 (undergraduate students)
- Helps maintain faculty skills

RAP-NIS Program

- Collaboration between RF and the U.S.
  - Increases broad understanding of nonproliferation
  - Joint research in nonproliferation issues important to U.S. and Russia
  - Extensive faculty interaction
  - Foreign field experience
  - Enhancing Russia/US relations
- Strong recognition and support by U.S. DOE
- Exceptional opportunities to extend network of next-generation nonproliferation and safeguards professionals


Russian Faculty at TAMU 2005


Distance Education to Ozersk Technological Institute 2010

Foreign Field Experience

- In NUEN 656, students have the opportunity to participate in the FFE
- Includes a week long tour of nuclear facilities in Europe in conjunction with students from MEPhI and IATE
- Serves to expose the students to
  - commercial nuclear facilities (reactors and fuel cycle facilities)
  - modern safeguards practices
  - cultural enrichment


2007 Switzerland


2010 UK


2006 France

The Role of Professional Societies

- Serve an important role in professional development of the student
  - leadership within the local chapter
  - exposure to professionals within the society
  - instilling the love of life-long learning within a professional community
  - learning the broader impacts of technological and political solutions

The Product of this Program

- Students produced from this program have
  - a strong disciplinary background in traditional nuclear engineering
  - ability to apply engineering principles to nuclear security issues
  - only an introduction to the policy aspects of nuclear security
- We focus on
  - safeguards and security system design and analysis,
  - nuclear safeguards and security technologies,
  - interaction between nuclear system design and security
- These students typically seek employment at US national laboratories, government, intelligence, and nuclear industry

Future Efforts

- We are working to establish certificates for students:
  - Certificate in Nuclear Forensics
  - Certificate in Nuclear Safeguards
  - Certificate in Nuclear Security
  - These will allow students to earn credit for taking only a subset of the courses offered
  - It would be enormously beneficial if these certificates could be "approved" by some competent authority
    - e.g., DOE, NNSA, NRC, IAEA, WINS, etc.
- Many of our students go on to complete PhD's but we don't have any specific nonproliferation related PhD courses
- We have considered adding a language component to the curriculum

Conclusions

- The TAMU degree program is well established
  - we have approximately 25 NUEN students in this program now
  - and another 20-30 students in other departments who gain some exposure to nonproliferation, safeguards, and security research
  - we have already shown a track record of placing our graduates into nonproliferation and safeguards careers at the national laboratories
- One key element for sustainability is strong research funding
  - funding for graduate students, especially to perform thesis research
- Students completing this program will be
  - the next generation of leaders in the fight to detect, prevent, and reverse the proliferation of nuclear and radiological weapons and combat nuclear terrorism

Backup Slides

Course Descriptions

NUEN 650 Nuclear Nonproliferation and Arms Control

- Lecture-based course studying the political and technological issues associated with nuclear nonproliferation and arms control
  - history of arms control and treaty verification regimes
  - descriptions and effects of weapons of mass destruction
  - the technology of nuclear weapons
  - proliferation pathways in the nuclear fuel cycle
  - international and domestic safeguards
  - proliferation resistance in the nuclear fuel cycle
  - nonproliferation strategies
  - nuclear terrorism
  - verifying the elimination of weapons programs
  - safeguards techniques for MPC&A

NUEN 605 Radiation Detection and Nuclear Material Measurements

- Laboratory and lecture course covering:
  - gamma-ray spectroscopy
  - alpha spectroscopy
  - neutron detection
  - uranium and plutonium gamma spectroscopy
  - uranium enrichment measurements
  - uranium holdup measurements
  - total neutron counting
  - coincidence neutron counting
  - active neutron interrogation
  - spent fuel measurements
  - handheld isotope identifiers
  - portal monitors

NUEN 651 Nuclear Fuel Cycles and Nuclear Material Safeguards

- Lecture course focusing on safeguards systems for all components of the nuclear fuel cycle and covers
  - legal basis for safeguards
  - international and domestic safeguard systems
  - Nuclear Material Accounting and Containment/Surveillance for fuel cycle facilities
  - Statistics
  - Bulk measurement methods
  - Chemical assay methods
  - Calorimetry
  - Application of NDA techniques to safeguards for fuel cycle facilities
  - Safeguards case studies (enrichment plant, CANDU Reactor, reprocessing plant, complete fuel cycle)

NUEN 656 Critical Analysis of Nuclear Security Data

- Project based course in which students must apply knowledge from their other courses to analyzing a particular nuclear security incident
- Small group projects that involve a nuclear security event
  - the students must analyze the data given and then ask for additional data and JIT lecture material to allow them to move forward with each project
  - the students are taught critical analysis techniques, learn how to work in small teams, and study how to use Red Team exercises to move each project forward
  - Sample projects:
    - Material diversion from commercial facility
    - Suspected weapons test
    - RDD seizure

NUEN 489 Nuclear Security Science

- Lecture-based course focusing on design and evaluation of systems to deter, detect, interdict, and neutralize threats to nuclear material
  - Analyze motivations and capabilities of adversaries
  - Characterize a Design Basis Threat (DBT)
  - Describe and explain the operation of detection, delay, and response technologies
  - Design a performance-based security
  - Produce a cost benefit analysis for upgrade options
  - Nuclear forensics as a component of a nuclear security
  - Discuss and critique the deterrence characteristics of nuclear security systems

MATH 664 Inverse Problems in Nuclear Forensics

- Theoretical results:
  - What data is sufficient to guarantee a unique reconstruction?
  - Inversion of ill conditioned problems
  - Can one show convergence and estimate rates of reconstruction algorithms?
  - How does data error contribute to the process?
- Final Project
  - Topic chosen by students to ensure compatibility
- Application areas covered
  - Inverse eigenvalue problems
    - recovery of key material parameters from knowledge of vibration modes
  - Inverse source problems
    - recovery of location, strength and geometry of sources from exterior measurements
  - Inverse scattering
    - detection of hidden inclusions in materials by measuring the scattered far field of an input wave
  - Tomographical reconstructions

CHEM 681 Radiochemistry and Nuclear Forensics

- Topics:
  - Electronic Configurations of Lanthanides and Actinides
  - Separation Techniques
  - Properties of Spent Fuel
  - Modern Reprocessing Techniques
  - Preparation and Characterization of Radioelement Compounds
  - Radiochemistry of Lanthanides
  - Transactinide Chemistry
  - Migration of Hot Particles in the Environment
  - Analysis of Samples After a Nuclear Incident
  - Mass Spectroscopy
  - Case Studies in Nuclear Forensics
- Lecturers included experts from throughout the DOE complex and other universities

Some Definitions

Some Definitions

- Nuclear nonproliferation is the field dedicated to stopping the spread of nuclear weapons, fissile material, and weapons-applicable technology
  - Arms control involves technical and policy measures to control the stockpiles of nuclear weapons with the eventual goal of complete and verifiable nuclear disarmament
- Nuclear safeguards are measures to verify that civil nuclear materials are properly accounted for and not diverted for undeclared uses and that nuclear facilities and technology are not misused for the purpose of producing a nuclear explosive device
- Nuclear security is the field to protect nuclear and other radioactive materials from theft and diversion, protect nuclear installations and transport against sabotage and other malicious acts, and to combat illicit trafficking in nuclear and other radioactive materials
  - Nuclear forensics the technical means by which nuclear materials, whether intercepted intact or retrieved from post-explosion debris, are characterized and interpreted